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S • E • C • T • I • O • N • 5

CASTINGS

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CHAPTER 5.1
CASTINGS MADE IN SAND MOLDS

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THE PROCESS

The making of a casting starts with the making of a pattern of the part to be cast. A refractory mold is then made from this pattern. The pattern is removed from the mold for reuse, and the cavity left by the pattern is filled with molten metal. When solid, the metal is the shape of the part. Figure 5.1.1 illustrates a mold as it would appear in a section view just after the metal has been poured.

The pattern is usually of wood for low production quantities, of aluminum for intermediate quantities, and of hard ferrous metals for high production. The "sand" refractory is usually a mixture of high purity: silica sand, bentonite clay, organic addi-

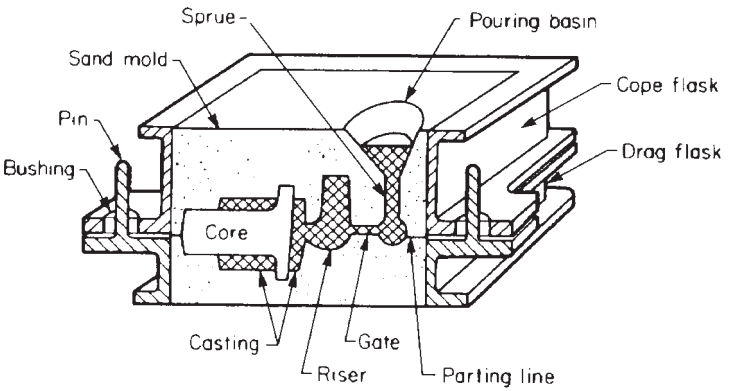

FIGURE 5.1.1 Typical mold arrangement for a sand-mold casting.

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tives, and water. This mixture is formed around the pattern by ramming and squeezing. Larger molds are dried to some degree before pouring. After the refractory has been compacted or chemically hardened, the mold is opened at a prearranged parting location and the pattern removed. Often the mold halves are made separately by using part of the pattern for each half. Accurate, strong sand components, called *cores,* are placed in the mold cavity to produce holes and internal cavities in the casting. The two halves of the mold are placed together by using pins and bushings for location. Metal is poured into the cavity through a previously prepared opening.

Green-Sand Molding

In this process, a moist, plastic, rammable refractory mixture is used. After ramming, removal of the pattern, and finishing, the mold is filled with metal while still in the damp, or green, state. This process can utilize the simplest hand ramming for short runs but usually is mechanized for intermediate quantities and is fully automatic for high production rates. Usually, the green-sand process is the most economical and is applicable to all but the largest castings.

Dry-Sand Molding

This process is similar to green-sand molding except that the molds are baked or dried before pouring. It is usually employed for multiton castings for which core and metal weights are great.

Cold-Cure Molding

This process uses chemical bonding of the sand by various organic and inorganic binders. These binders are blended into the sand immediately before it is placed on the pattern. The speed of chemical hardening can be regulated. The pattern is removed after hardening, and the mold is quite true to the pattern. Cold-cure molding is used on all sizes but predominantly on larger castings. Cores of all sizes, but especially large cores, also are made by this process. Costs and accuracy are greater than for green-sand molding.

Shell Molding

Shell molding is accomplished by coating a hot ferrous pattern with sand that has been mixed with a thermosetting plastic. This plastic, when heated, bonds the particles of sand together. At a predetermined time, any unhardened sand is removed, leaving a "shell" of bonded sand on the pattern to be completely cured. After hardening, the shell, 10 to 20 mm (0.4 to 0.8 in) thick, is ejected from the pattern. Two half-shell molds are mated together and glued. The mold can be filled while resting either horizontally without backup material or vertically with a packed shot or sand backing.

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Complicated casting shapes increase the strength and therefore the accuracy of the mold. This process is the most accurate of the sand-casting methods and is generally used for small, complicated parts for which accuracy is important. Accurate cores for all types of molding are made by this process if quantities or the desire for accuracy are great enough.

Lost-Foam (Evaporative Pattern) Molding

This is a process in which a polystyrene foam pattern, embedded in green sand, is not removed prior to pouring of the molten metal. Instead, the pattern vaporizes from the heat of the molten metal. The metal replaces the foam and takes the shape of the mold cavity.

The pattern is coated with a permeable refractory coating, which is dried before the pattern is placed in the mold flask. Loose sand is then introduced to the flask. Vibration is normally used to compact the sand around the pattern, and a vacuum may be applied to the mold during pouring.

The foam pattern is made by introducing partly expanded pellets of polystyrene material into a metal mold. Steam heat expands and softens the pellets so that they fill the mold and take its shape. The mold is cooled, and the part is ejected. Gating and multiple patterns may be glued together prior to the casting process.

Lost-foam molding has several advantages: (1) The process does not require two mold halves (there are no parting-line problems), (2) the part can be more intricate and have a better surface finish than that producible in the normal sand-molding process, (3) cores are not required, (4) cleaning is greatly reduced, and (5) there is less labor content in the process.

TYPICAL CHARACTERISTICS OF SAND-CAST PARTS

Complex castings can be made with casting processes using sand molds. Sand-mold casting has particular advantages when complicated shapes and differing section sizes are encountered. Intricate shapes with undercuts, reentrant angles, and complex contours, which would be very difficult to machine, are practicable to cast by sand-mold methods.

Another advantage of this method is that through stress-analysis techniques the designer can reassess his or her product. Usually, metal can be removed in areas of low stress and added in areas of high stress with relatively simple alterations to the pattern. This is especially true when prototypes are being made and when wood patterns are used.

The sizes of sand castings vary from about 30 g (1 oz) to 200 tons or more. However, foundries usually specialize in a particular size range. The section size depends to some extent on the metal.

Almost any metal that can be melted can be cast. Mold-metal reactions are limiting factors for a few materials. Table 5.1.1 lists metals commonly cast in sand molds.

Sand-mold castings have somewhat irregular, grainy surfaces. Dimensional variations should be expected in as-cast surfaces, and machining is normally required if

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TABLE 5.1.1 Metals Commonly Cast in Sand Molds

Designation		Tensile strength,	
Common	UNS	MPa (ksi)*	Remarks
		Cast iron	
G1800	F10004	124 (18)	Used where high strength is not a requirement; best machinability, damping properties, and resistance to thermal stress
G2500	F10005	172 (25)	Used for small cylinder blocks, pistons, gear boxes, clutch plates, and light-duty brake drums
G4000	F10008	275 (40)	Used for diesel engine cylinders, camshafts, pistons, and liners; best strength and wear resistance of these three cast irons
		Ductile iron	
60-40-18	F32800	410 (60) 275 (40) (Y)	Used for auto crankshafts, hubs, parts requiring shock resistance
		Magnesium	
AZ63A	M11630	200 (29) 130 (19) (Y)	Good castability; general casting alloy having good strength, ductility, and toughness
AZ92A	M11920	170 (25) 130 (19) (Y)	Pressure-tight components with good tensile and yield strength
		Copper alloys	
Leaded semired	C84400	235 (34) 103 (15) (Y)	For low-pressure valves and fittings, hardware parts, brass plumbing fixtures; machinability rating: 90% of C36000
Leaded red brass	C83600	255 (37) 117 (17) (Y)	Good general-purpose casting alloy; used for fire-equipment fittings, small gears, small pump parts; machinability: 84% of C36000
High-lead tin bronze	C92200	275 (40) 138 (20) (Y)	Valves, flanges, pump parts, gears, bushings
		Aluminum	
C355.0	A33550	248 (36) 172 (25) (Y)	Crankcases, gear housings air compressors, fittings
A356.0	A13560	234 (34) 165 (24) (Y)	Auto oil pans, transmission cases, real axle housings
B443.0	A24430	117 (17) 41 (6) (Y)	Marine fittings, pipe fittings, cooking utensils; very good castability
		Stainless steel	
CF-8M	J92900	550 (80) 290 (42) (Y)	Similar to wrought 316; used for aircraft parts, chemical processing, electronics, nuclear equipment, food processing, mining, fertilizer equipment, missiles

moving contact with other parts is involved or if seals are required. Most sand-cast metals (e.g., iron, aluminum, magnesium, and brass) are freely machinable.

Cast components are usually stable, rigid, and strong compared with parts made by

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TABLE 5.1.1 Metals Commonly Cast in Sand Molds (*Continued*)

Designation		Tensile strength,	
Common	UNS	MPa (ksi)*	Remarks
		Stainless steel (*Continued*)	
CF-8	J92600	531 (27) 255 (37) (Y)	Similar to wrought 304; used for aerospace castings, beverage, nuclear power, pharmaceutical, and chemical equipment
CA-15	J91150	793 (115) 690 (100) (Y)	Similar to wrought 410; used for jet engine parts, gears, bushings, liners, furnace burners, ship propellers, valve bodies
		Nickel alloys	
Nickel CZ-100 alloy		345 (50) 124 (18) (Y)	Standard grade nickel casting alloy with excellent castability; used for pressure tight components, pumps, valves, equipment for processing caustics at elevated temperatures
M-35-1 (Monel)		448 (65) 172 (25) (Y)	Pumps, valves, fittings; used with wrought nickel-copper alloys
		Carbon and alloy steel	
Carbon and low-alloy steels available in wrought form also can be sand-mold cast. Applications include those where greater strength, toughness, or wear resistance are required compared with that providable with cast irons. Tensile strengths range from 60 to 100 ksi for carbon steels and from 70 to 200 ksi for low-alloy steels. The bulk of casting output consists of medium-carbon steels. Uses for steel castings include parts for trucks, trailers, agricultural and earth-moving machinery, and machine tools and equipment for process industries and mining. Some representative steel casting alloys are the following: SC1020, SC1045, SC4140, SC8620, SC8630, and ASTM Spec. A356/A356M grades 1 and 2.			

*(Y) = yield point.

other processes. Cast iron has excellent sound- and vibration-damping properties.

Sand-mold castings are typically used for machine-tool bases, structures, and other components, pump housings, internal-combustion-engine blocks and cylinder heads, transmission cases, gear blanks, crankshafts, connecting rods, and many other machine components.

Figures 5.1.2 and 5.1.3 illustrate typical industrial castings.

ECONOMIC PRODUCTION QUANTITIES

Depending on the mold-making method used, sand-mold casting can be an economical means of production of applicable parts at all quantity levels. The processes used to produce sand molds for castings vary from simple hand ramming to completely automatic methods. In between, various amounts of mechanical assistance and semiautomatic equipment are used. If only a few pieces are required, a foundry with a minimum of mechanization often can give the lowest price. Automotive-type quantities

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FIGURE 5.1.2 This turbine manifold is an example of the complexity of part that can be produced by sand-mold casting. (*Courtesy Meehanite Worldwide Division of Meehanite Metal Corporation.*)

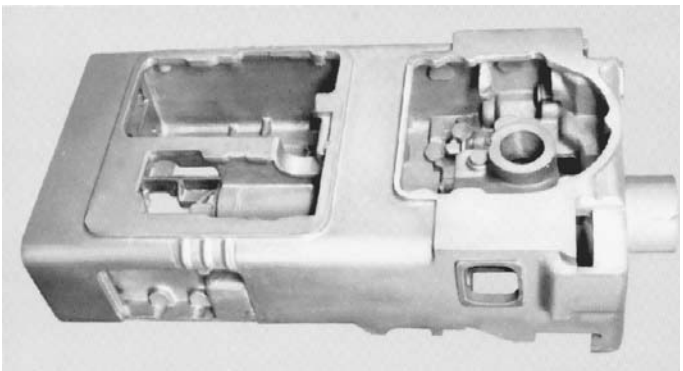

FIGURE 5.1.3 Cast-iron machine housing. (*Courtesy Meehanite Worldwide Division of Meehanite Metal Corporation.*)

require highly automated systems.

The cost of a casting includes the amortization of the pattern cost together with the manufacturing labor, metal, and overhead costs. With short runs, the pattern may be made of wood inexpensively. Even this low cost, however, spread over only a few pieces, might be quite high on a per-unit basis. High production runs require more expensive metal patterns to withstand the wear of repeated use. Such patterns, howev-

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er, would entail a low cost when divided among many pieces.

Frequent, small orders require setup time. Handling of small orders is expensive. Making a few prototype castings can easily involve a unit cost 10 times as high as that of the same casting made in substantial quantities. Larger quantities per order should permit a lower price.

A light-sectioned, rangy casting will always cost more per unit of weight than the same weight in a chunk. The difference can be as much as 4:1.

When obtaining quotations for castings, the designer should accurately estimate the weight. This weight should be used by all quoting foundries. The foundry should quote a piece price with a differential (metal cost only) for the difference between the actual and the estimated weight.

DESIGN CONSIDERATIONS AND RECOMMENDATIONS

Almost any shape that is designed can be cast. The problem is one of economics. A small consideration in design may mean substantial differences in costs. Consult the foundry early in the design stage when changes are easy. If the designer has several alternatives, discuss these. The foundry representative usually can determine which is the cheapest for the foundry to produce. The representative often is able to suggest changes that mean little in the design but which cut the casting cost or increase reliability.

Shrinkage

TABLE 5.1.2 Shrinkage Allowance for Metals Commonly Cast in Sand Molds

Metal	Percent
Gray cast iron	0.83–1.3
White cast iron	2.1
Ductile cast iron	0.83–1.0
Malleable cast iron	0.78–1.0
Aluminum alloys	1.3
Magnesium alloys	1.3
Yellow brass	1.3–1.6
Gunmetal bronze	1.0–1.6
Phosphor bronze	1.0–1.6
Aluminum bronze	2.1
Manganese bronze	2.1
Open-hearth steel	1.6
Electric steel	2.1
High-manganese steel	2.6

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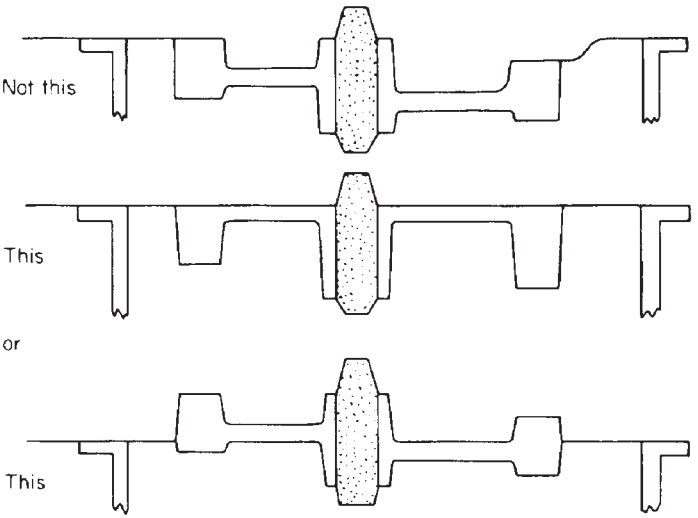

FIGURE 5.1.4 Straight parting lines are more economical than stepped parting lines.

A factor affecting sand-mold and other castings is the natural shrinkage of cast metal as it cools and solidifies. As well as reducing workpiece dimensions compared with the size of the mold cavity, it can cause induced stresses and distortion. The amount of shrinkage varies with different metals, but it is predictable and can be compensated for by making patterns slightly oversize. Table 5.1.2 lists normal shrinkage for metals frequently sand-cast.

Parting Line

The *parting line* is a continuous line around a part that separates the two halves of the mold. It is more economical and more accurate if the parting line can be on a flat plane, as shown in Fig. 5.1.4. Contoured parting lines usually result in fewer parts per mold, more costly patterns, less accuracy, more difficult "debugging," higher losses, and a need for more skilled molders, all of which increase costs. The greater the degree of contouring, the greater are the problems and costs.

Figure 5.1.5 illustrates an example in which a designer was able to redesign a part to eliminate an undercut. This permitted the use of a simpler pattern with the parting line coincident to a flat plane of the part instead of across its center. A flatter, more economical flask also could be used.

Draft

Each pattern must be easily removable from the weak, brittle molding sand. To facilitate removal, the pattern must have some degree of taper, or draft. With little or no

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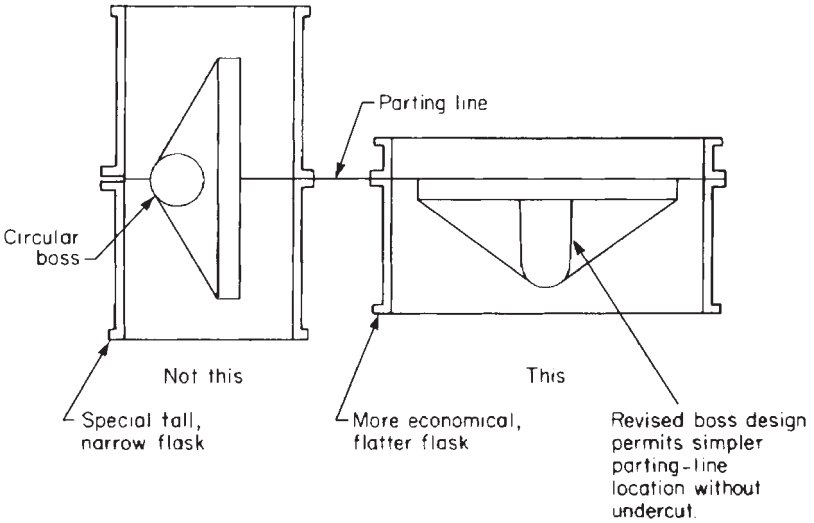

FIGURE 5.1.5 Elimination of an undercut on this casting permitted the use of a standard flask and a more straightforward parting-line location.

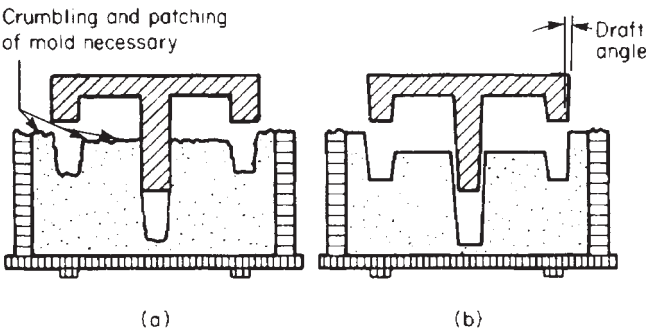

FIGURE 5.1.6 (*a*) Poor stripping from the mold results when no allowance is made for draft. (*b*) Ample draft permits easy and safe stripping.

draft, the pattern tends to tear the mold rather than slipping out smoothly. (See Fig. 5.1.6.) Castings having no draft or with undercuts can be made only by incorporating in the mold separately made, added cores at additional expense.

The amount of draft needed is related to the method of molding and drawing of the pattern, the material the pattern is made from, the degree of precision, and the surface smoothness of the pattern. In high-production work, the draw mechanism, being quite accurate, allows the pattern to be drawn if it is of high quality even if it has little draft.

The less the draft, the higher is the quality of the pattern needed and the greater is the cost. In high production, the higher pattern cost often can be easily saved in metal

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TABLE 5.1.3 Draft Angles for Outside Surfaces of Sand-Molded Castings*

	Pattern material					
	Wood		Aluminum		Ferrous	
	Pattern-quality level					
Ramming method	Normal	High	Normal	High	Normal	High
Hand	5°	3°	4°	3°		
Squeezer	3°	2°	3°	2°		
Automatic			2°	1°	1½°	½°
Shell molding					1°	¼°
Cold cure	3°	2°	2°	1°		

*The draft on inside surfaces should be twice that on the outside.

weight. Table 5.1.3 presents recommended draft angles for sand-molded castings (and patterns) under various conditions.

Casting Soundness

With most casting metals, we must consider liquid-to-solid shrinkage. This shrinkage can leave a void at the last point to solidify. Near that point, usually in a heavy section, the foundry operator adds a riser (reservoir) designed to contain metal hotter than the

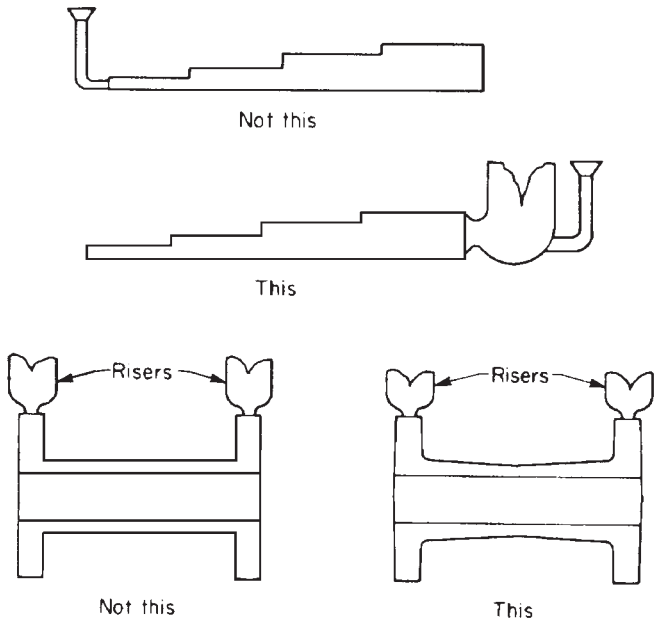

FIGURE 5.1.7 Incorrect and correct designs of castings and riser location to facilitate void-free filling of molds.

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casting. The riser supplies metal to the casting during solidification and contains the final void. The riser is removed later, leaving a solid casting.

By considering risering in the original design, the engineer can make the part easier to produce and reduce rejects and, therefore, costs. Risers are attached to the heaviest sections. All surrounding sections should be thinner. The thinnest sections are farthest from the riser and solidify first. Solidification progresses toward the heaviest section and then the riser. The designer should visualize the direction of solidification and taper sections as necessary to ensure that solidification proceeds toward the direction of risers, thus minimizing the chance for voids to occur. Figure 5.1.7 illustrates good and bad practice.

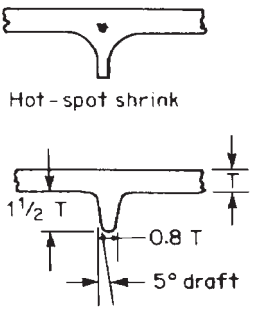

FIGURE 5.1.8 Incorrect and correct casting-rib design.

When walls cannot be graduated with respect to a riser location, the next best approach is to have even wall thickness and allow the foundry operator to control the heat gradient with the metal flow.

Ribs and Webs

These are effective in providing increased stiffness to a component with a minimum increase in weight. Figure 5.1.8 illustrates desirable proportions for stiffening ribs. Heavier sections where the rib intersects the casting wall can cause hot-spot shrinks as shown.

The number of ribs intersecting at one

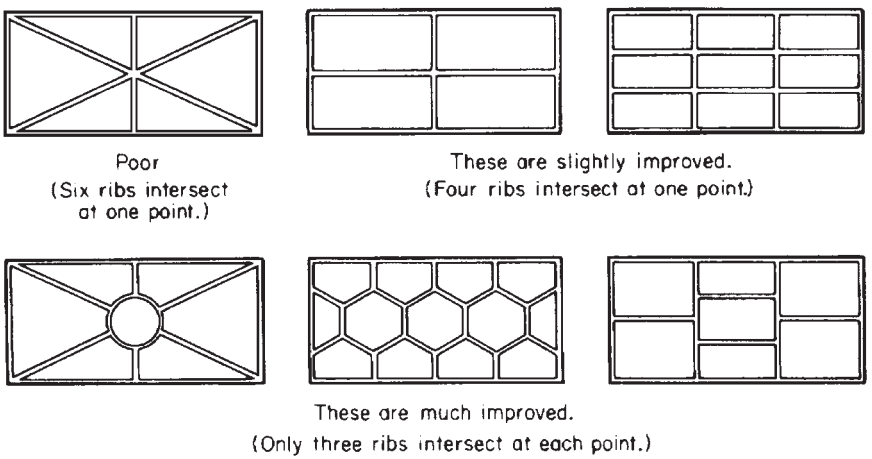
Poor
(Six ribs intersect at one point.)
These are slightly improved.
(Four ribs intersect at one point.)
These are much improved.
(Only three ribs intersect at each point.)

FIGURE 5.1.9 Reduce the number of reinforcing ribs that intersect at one point so as to reduce the necessary thickness at the intersection. This helps prevent voids at the intersection.

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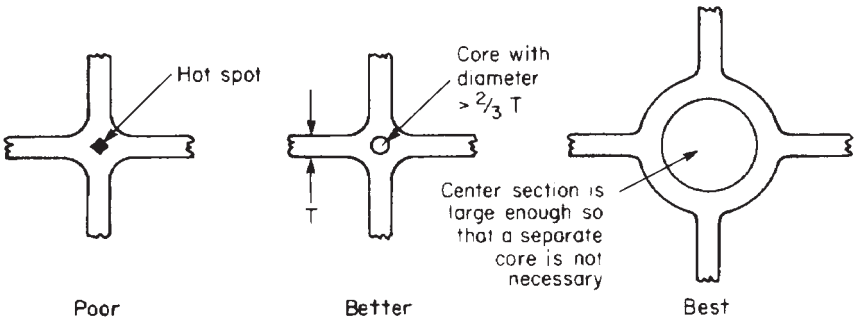

FIGURE 5.1.10 Design alternatives to prevent hot-spot voids at rib and casting wall intersections.

point should be minimized to avoid hot-spot effects. (See Fig. 5.1.9.) When it is necessary to bring a number of ribs or other members together at one point, a cored hole at the point of intersection will help to speed solidification. This will prevent shrink voids and structural weakness and distortion. A preferable alternative is to use a circular web to connect the ribs, thus avoiding the need for a core piece. Figure 5.1.10 illustrates these solutions.

Corners and Angles

Hot spots are the most common defect in casting design. They cause weak zones and points of high stress. There are many variations of this problem.

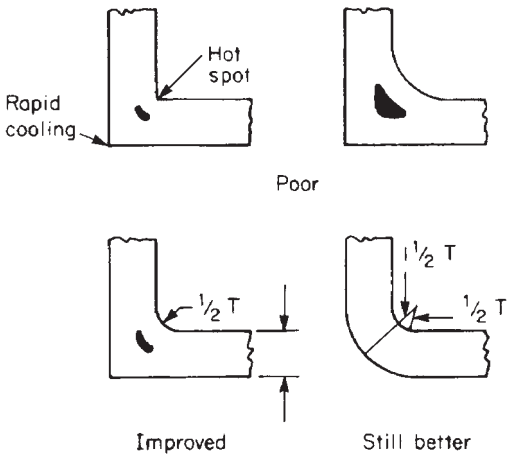

FIGURE 5.1.11 Sharp corners cause uneven cooling and molded-in stress, while rounded corners permit uniform cooling with much less stress. Rounded corners that maintain uniform wall thickness provide the best results.

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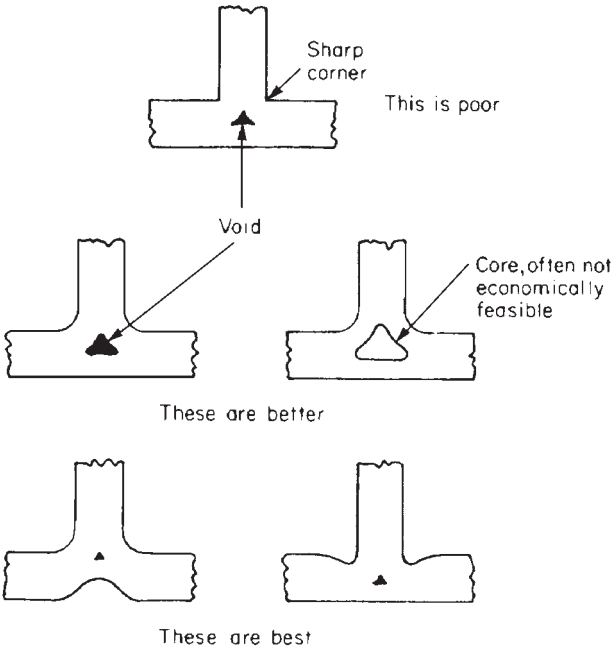

FIGURE 5.1.12 Incorrect and correct design of T joints in castings.

The crystal growth of solidifying metal progresses inward from each surface. Outside corners radiate heat in two directions and cool quickly. Inside corners heat the sand in the corner from two directions, creating a hot spot that retards solidification. Rounding of corners of all types avoids local structural weakness, as shown in Fig. 5.1.11. Rounding the inside corners decreases the severity of the hot spot and lessens the stress concentration. However, too much rounding will promote a shrink defect in a corner. Rounding both the inside and the outside of the corner and using the same center for the radii are better.

In a T section, as illustrated in Fig. 5.1.12, a dished contour opposite the intersecting member minimizes the shrink so that larger inside radii can be used to minimize stress concentration and hot spots. Two dished contours, one on each side of the center

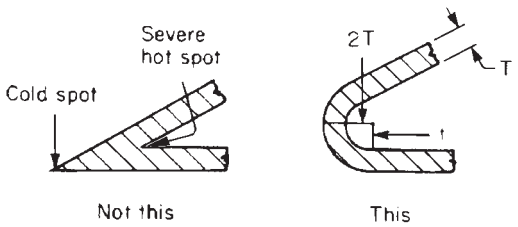

FIGURE 5.1.13 Sharp-corner acute angles cause areas of uneven cooling and should be avoided.

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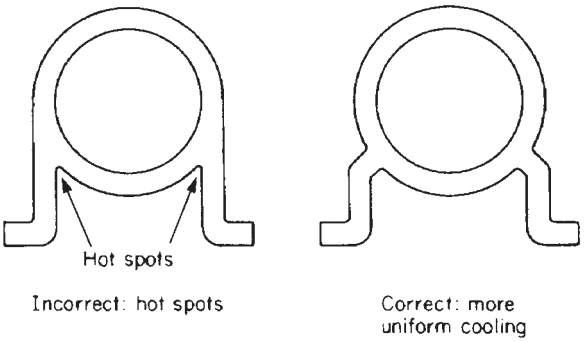

FIGURE 5.1.14 The intersection of two walls of a casting should be at right angles to avoid sharp-corner hot spots.

leg, are also effective.

The ultimate in removing the shrink area is to add a separately made core to the intersection. Except for "x-ray quality" work, however, this is more trouble and expense than it is worth. When the voids are minimized, they retreat to a zone of almost zero stress and are thus insignificant.

The more acute the angle, the greater is the problem, for both the rapid-cooling area and the hot-spot effect are increased. Figure 5.1.13 illustrates the cooling effect. The intersection of two walls of a casting should be at a right angle, if possible, to minimize heat concentration. Figure 5.1.14 illustrates an example.

TABLE 5.1.4 Minimum Economical Section Thickness for Green-Sand Castings*

Section length	To 300 mm (12 in)	To 1.2 m (6 ft)	To 3.6 m (12 ft)
Aluminum	3–5 mm (1/8–3/16 in)	8 mm (5/16 in)	16 mm (5/8 in)
Brass and bronze	2.4–3 mm (3/32–1/8 in)	8 mm (5/16 in)	16 mm (5/8 in)
Ductile iron	5 mm (3/16 in)	13 mm (1/2 in)	19 mm (3/4 in)
Gray iron, low strength	3 mm (1/8 in)		
Gray iron, 138-MPa (20,000-lbf/in^2) tensile strength	4 mm (5/32 in)	10 mm (3/8 in)	
Gray iron, 207-MPa (30,000-lbf/in^2) tensile strength	5 mm (3/16 in)	10 mm (3/8 in)	19 mm (3/4 in)
Gray iron, 276-MPa (40,000-lbf/in^2) tensile strength	6 mm (1/4 in)	13 mm (1/2 in)	25 mm (1 in)
Gray iron, 345-MPa (50,000-lbf/in^2) tensile strength	10 mm (3/8 in)	16 mm (5/8 in)	25 mm (1 in)
Magnesium alloys	4 mm (5/32 in)	8 mm (5/16 in)	16 mm (5/8 in)
Malleable iron	3 mm (1/8 in)	6 mm (1/4 in)	
Steel	8 mm (5/16 in)	13 mm (1/2 in)	25 mm (1 in)
White iron	3 mm (1/8 in)	13 mm (1/2 in)	19 mm (3/4 in)

*Thinner walls are economical in shell, dry-sand, or cold-cure molded castings. Some designs of castings lend themselves to thinner walls without problems.

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CASTINGS MADE IN SAND MOLDS

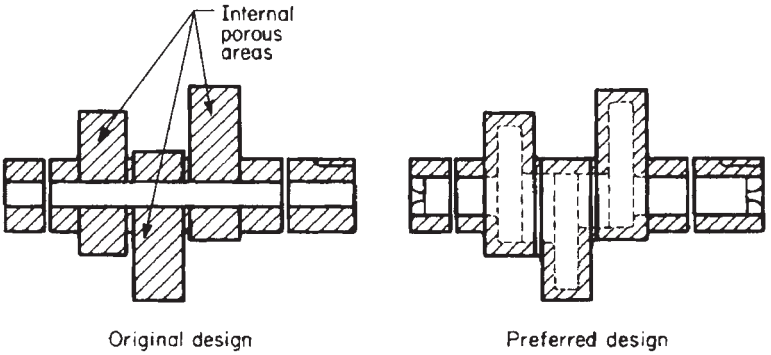

FIGURE 5.1.15 Keeping wall thicknesses uniform promotes sounder castings because heavy sections are more prone to internal porosity.

Wall Thickness

Table 5.1.4 shows the normal minimum economical wall thickness for various metals. In general, problems increase rapidly if sections are too small [under 6 mm (¼ in)] in all metals. It is often cheaper to increase the section size than to pay an increased price required to cover foundry scrap losses. The farther the metal must flow in the mold, the heavier the section must be. Therefore, there is a limit to the savings that are gained by reducing the weight of a casting. Heavy sections also can cause problems, especially if they are isolated, as described above.

It is best to have sections and walls as uniform as possible in thickness. This avoids problems with voids and porosity in heavy sections and added stresses or distortion due to uneven cooling. Figure 5.1.15 illustrates a typical example.

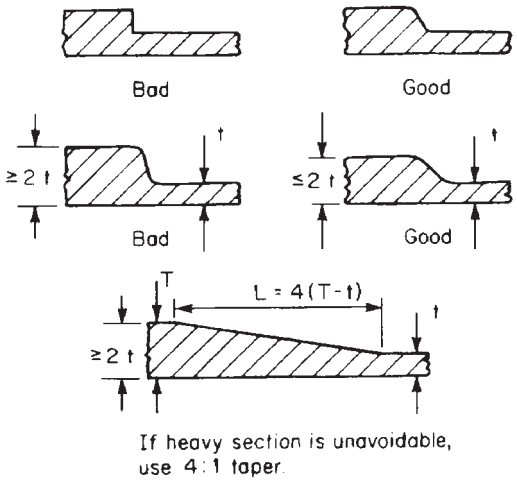

FIGURE 5.1.16 Design rules for areas where section thickness must change.

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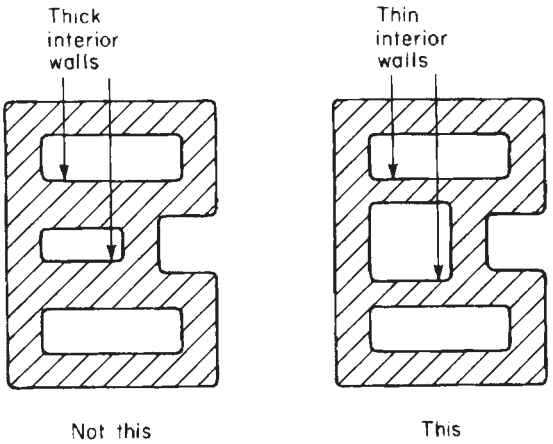

FIGURE 5.1.17 Interior walls should be 20 percent thinner than exterior walls since they cool more slowly.

Section Changes

Abrupt changes in sections should be avoided. Fillets and tapers are preferable to sharp steps. Normally, a difference of greater than 2:1 in relative thickness of adjoining sections should be avoided. If a section change of over 2:1 is unavoidable, the designer has two alternatives: (1) Design the section as two separate castings to be bolted together later, or (2) use a wedge form between the unequal sections. The taper of the wedged area should not exceed 1:4. Figure 5.1.16 illustrates these points.

Interior Walls and Sections

These walls and sections should be 20 percent thinner than the outside members because they cool more slowly than the external walls. In this way, thermal and residual stresses are reduced and metallurgical changes are minimized (Fig. 5.1.17).

Lightener Holes

To reduce weight in low-stressed areas, lightener holes can be added. These in themselves can be stress raisers if they have sharp corners.

Holes and Pockets

The incorporation of through holes and pockets (cavities) in sand-mold castings is straightforward and economical. If these are located so that they can be produced by the mold rather than by an extra core, they may reduce the cost of the casting by saving material.

With green-sand molding, the so-called green-sand core is very weak. It will break

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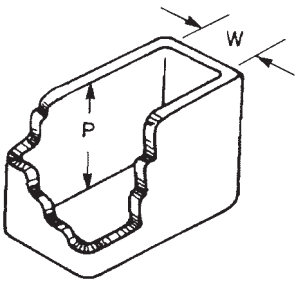

FIGURE 5.1.18 Design rules for the correct proportions of rectangular pockets or holes in castings: $P \leq 1\frac{1}{2}\ W$ if in drag; $P \leq W$ if in cope.

if touched by the pattern during the draw. The rule, therefore, is that the draft on the inside of a pocket must be twice as much as on the surrounding outside surfaces. This outside acts as a guide during the drawing of the pattern. Another rule is that the depth of a hole or pocket should not be more than $1\frac{1}{2}$ times its narrowest dimension if it is in the drag (bottom) half of mold; this depth should be no more than the narrowest dimension if the hole or pocket is in the cope (top) half of the mold. Figure 5.1.18 illustrates this rule.

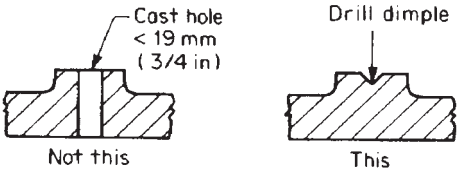

FIGURE 5.1.19 Holes less than 19 mm ($\frac{3}{4}$ in) in diameter are cheaper and better if drilled after casting.

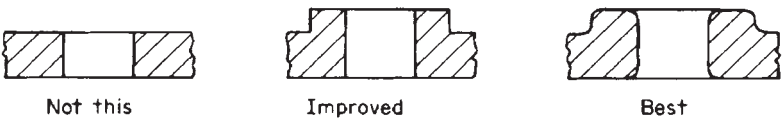

FIGURE 5.1.20 When a hole is placed in a highly stressed section, add extra material around the hole as a reinforcement.

Small holes are generally not economical to mold or core. It is usually cheaper and more satisfactory to drill them. The break-even point is between 13- and 25-mm ($\frac{1}{2}$- and 1-in) diameter. A drill dimple can be cast in the part to facilitate offhand drilling if applicable, as shown in Fig. 5.1.19.

With shell molding, pockets that are much deeper than their width can be drawn with high-quality pattern equipment. This can justify the more expensive shell process.

Holes are generally stress raisers, and they should have extra metal around them to compensate. This metal should be carefully blended to minimize hot spots and stress-raising corners. (See Fig. 5.1.20.)

Bosses and Pads

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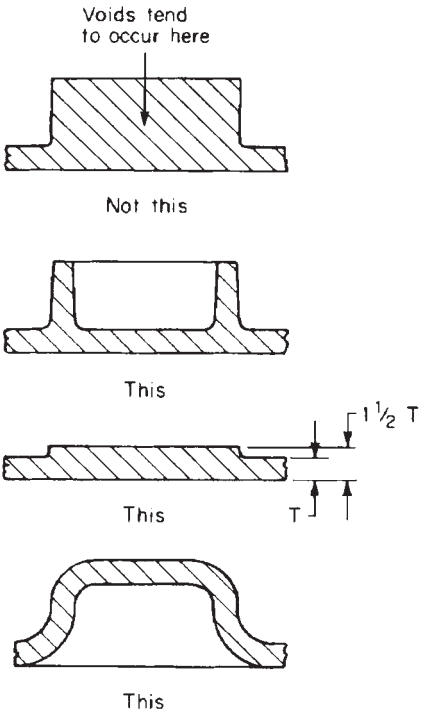

FIGURE 5.1.21 Design suggestions for minimizing material thickness at bosses.

These small raised areas are usually necessitated to minimize surface machining. If too large, they create voids and hot spots. Because of these problems, bosses, pads, and lugs should be minimized. Figure 5.1.21 illustrates workable alternatives.

Cores

Cores are subject to heat and high floating pressures. Their usual organic binders break down, releasing gases that must be vented to prevent bubbles in the metal. The decomposed sand must be removable by cleaning processes. More significantly, cores are expensive to make, handle, set in the mold, and clean out later. For these reasons they should not be used if at all avoidable. Figure 5.1.22 illustrates some economical alternatives.

Small cores in heavy sections are extremely hard to remove. If small, round holes are required, it is almost always cheaper and more satisfactory to drill them. The core should have a diameter at least equal to the surrounding wall thickness and preferably twice the wall thickness or more. (See Fig. 5.1.23.)

Side bosses and undercuts normally necessitate the use of cores as part of the mold. Since cores add significantly to the cost of castings, it behooves the designer to eliminate side bosses and undercuts from casting designs. Figure 5.1.24 illustrates exam-

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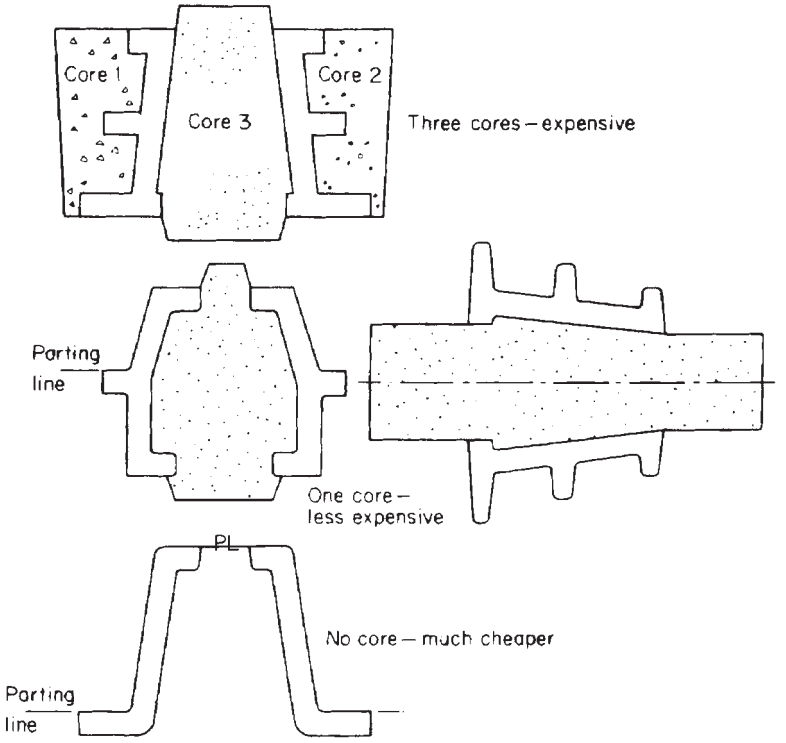

FIGURE 5.1.22 Minimize the need for cores as much as possible by eliminating undercuts.

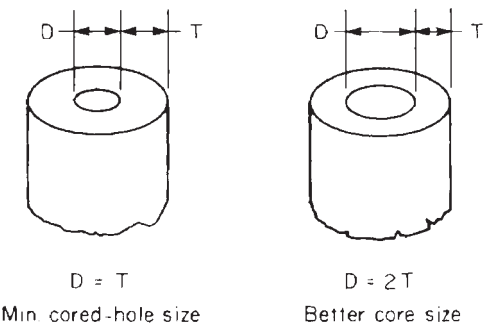

FIGURE 5.1.23 Small cored holes should be avoided since removal of core material after casting is costly.

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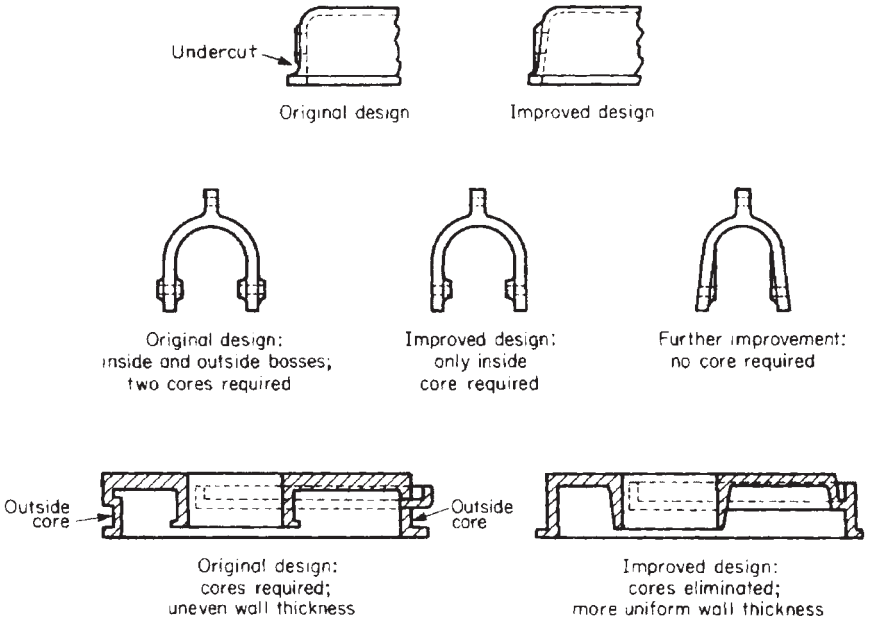

FIGURE 5.1.24 External undercuts frequently necessitate the use of separate mold core pieces. Illustrated are three parts that were redesigned to eliminate the need for such cores without reducing the function of the parts.

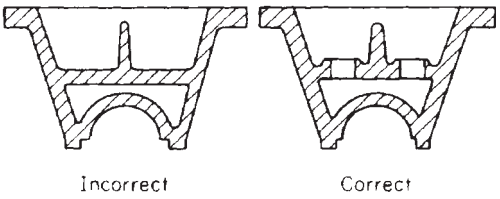

FIGURE 5.1.25 Internal pockets in castings may require cored vent holes to allow gases released during pouting to escape and to facilitate cleaning after casting.

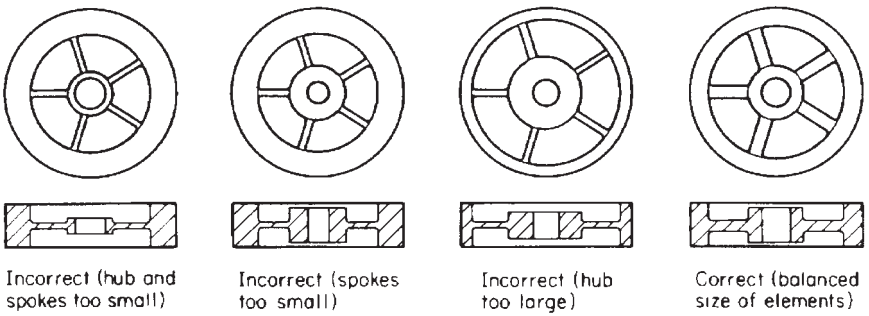

FIGURE 5.1.26 Incorrect and correct proportions of elements of pulleys and gear blanks.

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CASTINGS MADE IN SAND MOLDS

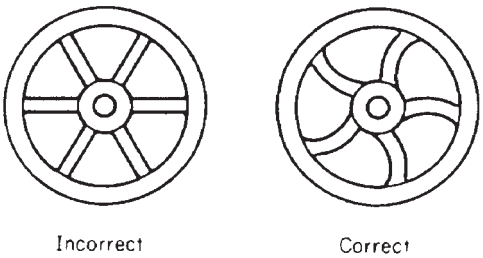

FIGURE 5.1.27 An odd number of curved wheel spokes helps dissipate cast-in stresses.

ples of various components for which this was done.

Internal cores require adequate provision for removing the gases generated when the core comes in contact with the molten metal. Figure 5.1.25 illustrates the addition of venting holes to a particular casting for this purpose and to facilitate removal of the core sand.

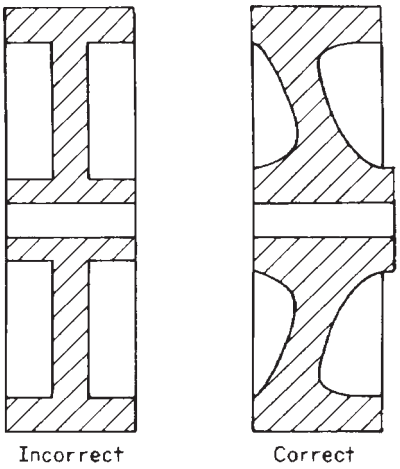

FIGURE 5.1.28 Carefully blended curved webbing also dissipates cast-in stresses in wheels, pulleys, and gear blanks.

Gears, Pulleys, and Wheels

These apparently simple objects are often improperly designed. Residual casting stresses involved can markedly reduce their strength, resulting in premature breakage. To minimize the stresses, a balance between the section size of the rim, spokes, and hub must be attempted. (See Fig. 5.1.26.) It is also desirable to have an odd number of spokes. Curved spokes as shown in Fig. 5.1.27 dissipate additional stress. Solid webbed wheels can have dished surfaces that allow the stress to be reduced. In this case, excessive section variation is to be avoided (see Fig. 5.1.28).

Lettering and Other Data

Any lettering should be parallel to the parting plane so that the mold pockets for the letters will draw. When placed in any other position, the lettering would require an expensive core.

Such data as part numbers, date of casting, foundry trademark, cavity number, and sometimes serial numbers, etc. all need a place on the casting. These must be in a position where they will not interfere with machining. They can be either sunken or raised above the surface.

Weight Reduction

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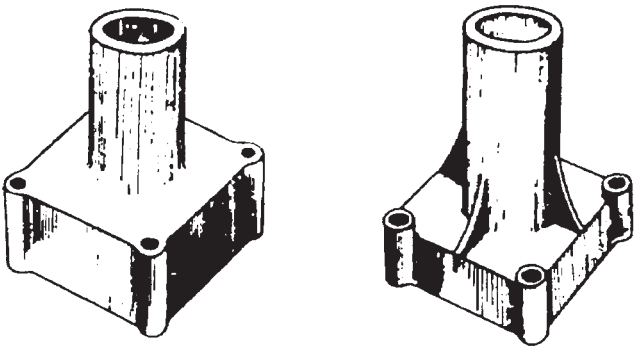

FIGURE 5.1.29 A hydraulic-ram head was reduced in cost when the casting was redesigned to require less material.

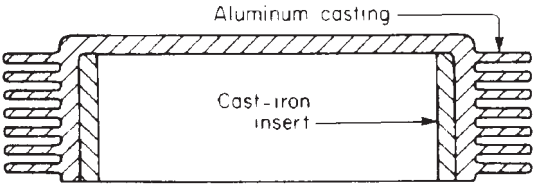

FIGURE 5.1.30 A cast-iron wear-surface insert in an aluminum aircraft-brake casting.

Economies of production are realized when, consistent with functional requirements, casting weight is minimized. An advantage of sand-mold casting is that in the prototype state easily changed wooden patterns are used. The information about low- and high-stressed areas can be determined by stress analysis of prototype castings, and metal can be removed from low-stressed areas and added to high-stressed areas by way of an inexpensive pattern change, often of wax. Many examples may be found for cutting weight 20 to 50 percent while increasing strength 50 to 100 percent through this technique. (See Fig. 5.1.29.)

Inserts of Different Metals

It is sometimes desirable to incorporate a section of a different metal, either harder or softer than the base metal, in a casting. This can be done and may save money. An example is the cast-aluminum aircraft brake of Fig. 5.1.30 with a cast-iron wear surface included as an insert. Various metal combinations can be used. Most are held in the casting more by mechanical interlocking than by metallic fusion. The inserts must have projections to prevent turning or lateral movement. These inserts are not generally pressure-tight unless sealed after casting.

Design to Facilitate Machining

Castings designed with sharp angles or edges are a common source of machine-shop trouble. This is caused by the faster cooling of the corner section at the joint and is

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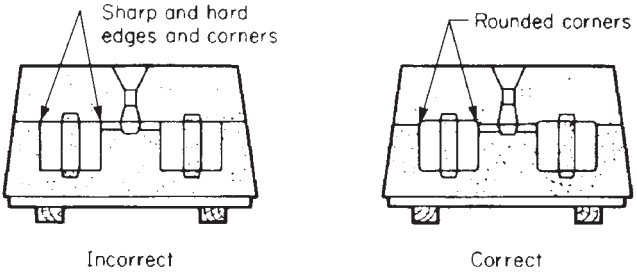

FIGURE 5.1.31 Avoid sharp corners and fins in areas to be machined after casting.

TABLE 5.1.5 Allowance for Machining: Each Side

		Allowance, mm (in)	
	Casting size, mm (in)*	Drag and sides	Cope surface
Gray iron	Up to 150 (up to 6)	2.3 (3/32)	3 (1/8)
	150–300 (6–12)	3 (1/8)	4 (5/32)
	300–600 (12–24)	5 (3/16)	6 (1/4)
	600–900 (24–36)	6 (1/4)	8 (5/16)
	900–1500 (36–60)	8 (5/16)	10 (3/8)
	1500–2100 (60–84)	10 (3/8)	13 (1/2)
	2100–3000 (84–120)	11 (7/16)	16 (5/8)
Cast steel	Up to 150 (up to 6)	3 (1/8)	6 (1/4)
	150–300 (6–12)	5 (3/16)	6 (1/4)
	300–600 (12–24)	6 (1/4)	8 (5/16)
	600–900 (24–36)	8 (5/16)	10 (3/8)
	900–1500 (36–60)	10 (3/8)	13 (1/2)
	1500–2100 (60–84)	11 (7/16)	14 (9/16)
	2100–3000 (84–120)	13 (1/2)	19 (3/4)
Malleable iron	Up to 75 (up to 3)	1.5 (1/16)	2.3 (3/32)
	75–300 (3–12)	2.3 (3/32)	3 (1/8)
	300–450 (12–18)	3 (1/8)	4 (5/32)
	450–600 (18–24)	4 (5/32)	5 (3/16)
Ductile iron	Up to 150 (up to 6)	2.3 (3/32)	6 (1/4)
	150–300 (6–12)	3 (1/8)	10 (3/8)
	300–600 (12–24)	5 (3/16)	19 (3/4)
	600–900 (24–36)	6 (1/4)	19 (3/4)
	900–1500 (36–60)	8 (5/16)	25 (1)
	1500–2100 (60–84)	10 (3/8)	28 (1 1/8)
	2100–300 (84–120)	11 (7/16)	32 (1 1/4)
Nonferrous metals	Up to 150 (up to 6)	1.6 (1/16)	2.3 (3/32)
	150–300 (6–12)	2.3 (3/32)	3 (1/8)
	300–600 (12–24)	3 (1/8)	4 (5/32)
	600–900 (24–36)	4 (5/32)	5 (3/16)

**Casting size* refers to the overall length of the casting and not to the length of a particular measurement.

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TABLE 5.1.6 Allowance for Machining Cylinders; Machining Located from the Bore*

Diameter, mm (in)	Range of allowance; total of both sides, mm (in)
0–25 (0–1)	3–4.5 (0.12–0.18)
25–100 (1–4)	3–5 (0.12–0.20)
100–200 (4–8)	4.5–6 (0.18–0.24)
200–300 (8–12)	5–8 (0.20–0.32)
300–600 (12–24)	6–10 (0.24–0.40)

Note: Use as a rough guide only.

*When machining location is other than the bore, additional stock may be necessary to compensate for allowable tolerance between locating points and bore.

accentuated by the presence of a fin or flash.

By rounding edges and corners sufficiently to eliminate chilling, the risk of hard corners or edges is avoided, and, in turn, machine-shop costs are reduced. When this is done, the parting should be made to permit all corners and edges to be rounded. (See Fig. 5.1.31.)

Machining Allowances

A stock allowance must be added to surfaces that are to be machined. The allowance provides for dimensional and surface variations in the as-cast workpiece. The amount of stock allowance depends on the size of the surface to be machined and also somewhat on the machining method and the final accuracy required.

If only flatness is desired and some unmachined areas are not objectionable, a minimum of additional metal is needed. If a fully machined surface without imperfections is necessary, more metal must be removed. Normal full allowances are shown in Table 5.1.5.

Casting shrinkage across a bore is less predictable than that for other dimensions. For this reason, it is difficult to make general recommendations for machining allowances for cylinder bores. The more bores to be machined per casting, the more variables there are, and therefore, more stock is allowed. The larger the casting, the more unpredictable is its size, and again, more allowance is made. Table 5.1.6 presents ranges of recommended allowances for cylinder-bore machining.

DIMENSIONAL FACTORS AND TOLERANCE RECOMMENDATIONS

Many factors influence the degree to which any particular cast piece differs in dimensions from those specified. These include differences in methods, equipment, metal, and sand from foundry to foundry or from lot to lot; variations in metal temperature, cooling time, and cooling conditions; and differences in mold hardness, pattern inaccuracies, shrinkage variations, internal stresses, and many more. Because of the effect of these factors in normal production, it is best not to specify tolerances any tighter

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TABLE 5.1.7 Typical Tolerances for Green-Sand and Oil-Sand Castings*

Location	Dimension	Tolerance
One side of parting line	0–25 mm (0–1 in)	±0.6 mm (±0.023 in)
	25–75 mm (1–3 in)	±0.8 mm (±0.030 in)
	75–150 mm (3–6 in)	±1.2 mm (±0.045 in)
	150–230 mm (6–9 in)	±1.5 mm (±0.060 in)
	230–300 mm (9–12 in)	±2.3 mm (±0.090 in)
	300–400 mm (12–16 in)	±2.6 mm (±0.102 in)
	400–500 mm (16–20 in)	±2.9 mm (±0.114 in)
	500–600 mm (20–24 in)	±3.2 mm (±0.125 in)
	600–760 mm (24–30 in)	±3.5 mm (±0.138 in)
	760–900 mm (30–36 in)	±3.8 mm (±0.150 in)
	Area at parting line	
Additional tolerance for dimensions across parting line (tolerance to be added to that above)	6–65 cm^2 (1–10 in^2)	±0.5 mm (±0.020 in)
	65–320 cm^2 (10–50 in^2)	±0.9 mm (±0.035 in)
	320–650 cm^2 (50–100 in^2)	±1.0 mm (±0.040 in)
	650–1600 cm^2 (100–250 in^2)	±1.3 mm (±0.050 in)
	1600–4000 cm^2 (250–600 in^2)	±1.5 mm (±0.060 in)
	4000–6500 cm^2 (600–1000 in^2)†	±2.0 mm (±0.080 in)
	Dimension	
Between two cores	0–75 mm (0–3 in)	±0.8 mm (±0.030 in)
	75–150 mm (3–6 in)	±1.5 mm (±0.060 in)
	150–230 mm (6–9 in)	±2.3 mm (±0.090 in)
	230–600 mm (9–24 in)	±3.0 mm (±0.120 in)
	600–1500 mm (24–60 in)	±4.5 mm (±0.180 in)
	Over 1500 mm (over 60 in)	±6.3 mm (±0.250 in)
Cores: shell, hot-box, cold-cure, etc. (one side of core box)‡	0–25 mm (0–1 in)	±0.15 mm (±0.006 in)
	25–50 mm (1–2 in)	±0.30 mm (±0.012 in)
	50–75 mm (2–3 in)	±0.45 mm (±0.018 in)
	75–150 mm (3–6 in)	±0.75 mm (±0.030 in)
	150–230 mm (6–9 in)	±1.0 mm (±0.040 in)
	230–300 mm (9–12 in)	±1.3 mm (±0.050 in)
	Over 300 mm (over 12 in)	±1.3 mm plus 0.2% (±0.050 in plus 0.2%)
Shift, mold or core; largest casting dimension *A* greater than smallest *B*	0–200 mm (0–8 in)	±2 mm (±0.080 in)
	200–450 mm (8–18 in)	±3 mm (±0.120 in)
	450–900 mm (18–36 in)	±5 mm (±0.190 in)
	900–1500 mm (36–90 in)	±6 mm (±0.250 in)

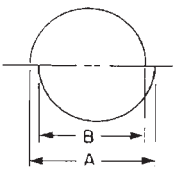

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TABLE 5.1.7 Typical Tolerances for Green-Sand and Oil-Sand Castings* (*Continued*)

Location	Angle	Tolerance
Draft angles		
Outside	1–3°	±½°
Cope (top)	3–7°	±½°
Drag (bottom)	2–6°	±½°
Oil-sand cores	2–5°	±½°
Shell-sand cores	½–3°	±¼°
	Dimension	
Wall thickness	3 mm (⅛ in)	±15%
	4–14 mm (3/32–9/16 in)	12½%
	15–25 mm (19/32–1 in)	±10%

*This table is primarily for gray iron but is applicable to other metals. Aluminum castings should be capable of holding 33% narrower ranges, while steel and copper alloys usually need 50% wider ranges. Molds made by cold-cure processes can be expected to hold tighter tolerances, up to 50% of the tolerances on one side of the parting line. However, they require more tolerance across the parting line.

†Over 900 mm, add 0.2%; over 36 in, add 0.002 in/in.

‡Add ±0.4 mm (±0.015 in) to these values if the dimension is across the core-box parting line; applicable to molds by these processes also.

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CASTINGS MADE IN SAND MOLDS

than absolutely necessary. Tight tolerances require more precise pattern making, a statistical checking program, reworking the pattern, and often 100 percent gauging with resulting scrap. The purchaser pays for all of this sooner or later.

When castings are dimensioned in inches, the general practice is to specify noncritical or nominal dimensions in fractions of inches or one- or two-place decimals. Critical dimensions are usually given as three-place decimals with a tolerance range.

Recommended tolerances are shown in Table 5.1.7. These are for average conditions. Under specific conditions, the ranges can be decreased

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